

The GRB/SN Connection: An Improved Spectral Flux Distribution for the SN-Like Component to the Afterglow of GRB 970228, the Non-Detection of a SN-Like Component to the Afterglow of GRB 990510, and GRBs as Beacons to Locate SNe at Redshifts $z \approx 4 - 5$

Daniel E. Reichart*, Donald Q. Lamb*, and Francisco J. Castander†

**Department of Astronomy & Astrophysics, University of Chicago,
5640 South Ellis Avenue, Chicago IL, 60637*

†Observatoire Midi-Pyrénées, 14 Av. Edouard Belin, 31400 Toulouse, France

Abstract. We better determine the spectral flux distribution of the supernova candidate associated with GRB 970228 by modeling the spectral flux distribution of the host galaxy of this burst, fitting this model to measurements of the host galaxy, and using the fitted model to better subtract out the contribution of the host galaxy to measurements of the afterglow of this burst. Furthermore, we discuss why the non-detection of a SN1998bw-like component to the afterglow of GRB 990510 does not necessarily imply that a SN is not associated with this burst. Finally, we discuss how bursts can be used as beacons to locate SNe out to redshifts of $z \approx 4 - 5$.

AN IMPROVED SPECTRAL FLUX DISTRIBUTION FOR THE SN-LIKE COMPONENT TO THE AFTERGLOW OF GRB 970228

The discovery of what appear to be SNe dominating the light curves and spectral flux distributions (SFDs) of the afterglows of GRB 980326 (Bloom et al. 1999) and GRB 970228 (Reichart 1999; Galama et al. 1999) at late times after these bursts strongly suggests that at least some, and perhaps all, of the long bursts are related to the deaths of massive stars. Here, we build upon the results of Reichart (1999) by modeling the SFD of the host galaxy of GRB 970228, fitting this model to measurements of the host galaxy, and using the fitted model to better subtract out the contribution of the host galaxy to measurements of the afterglow of this burst.

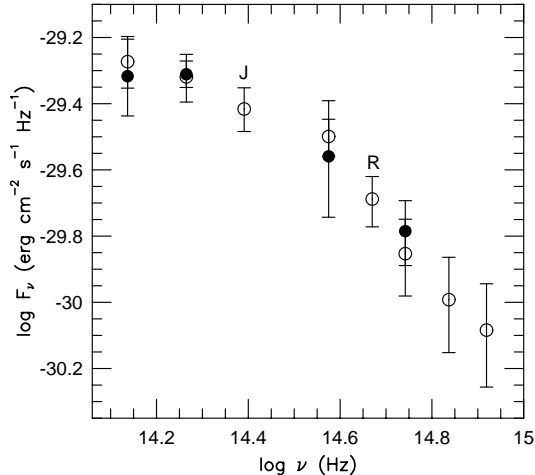


FIGURE 1. The observed (filled circles) and modeled (unfilled circles) K- through U-band SEDs of the host galaxy of GRB 970228.

In Figure 1, we plot the observed SFD of the host galaxy of GRB 970228, as measured with *HST*/WFPC2, *HST*/NICMOS2, and Keck I (Castander & Lamb 1999a; Fruchter et al. 1999). To these measurements and a broadband measurement made with *HST*/STIS (Castander & Lamb 1999a; Fruchter et al. 1999), which is not plotted, we fit a two-parameter, spectral synthesis model (see Castander & Lamb 1999a for details). The two parameters are the normalization of the SFD, and the age of the galaxy, defined to be the length of time that star formation has been occurring at a constant rate. Taking $A_V = 1.09$ mag for the Galactic extinction along the line of sight (Castander & Lamb 1999b), we find a fitted age of 270^{+460}_{-180} Myr; different values of A_V affect primarily the fitted age, and not the fitted SFD. Furthermore, models in which star formation slows considerably, or ceases, are generally too red to account for the measurements. Finally, we note that the fitted J- and R-band spectral fluxes are perfectly consistent with what one finds simply from linear interpolation between adjacent photometric bands.

In Figure 2 (left panel), we plot the SFD of the afterglow minus the *observed* SFD of the host galaxy from Figure 1. For the SFD of the afterglow, we use the revised K-, J-, and R-band measurements of Galama et al. (1999) and the I- and V-band measurements of Castander & Lamb (1999a; see also Fruchter et al. 1999); all of these measurements were taken between 30 and 38 days after the burst. We have scaled these measurements to a common time of 35 days after the burst, and have corrected these measurements for Galactic extinction along the line of sight (see Reichart 1999 for details). The K-band measurement of the afterglow is consistent with that of the host galaxy (Galama et al. 1999), resulting in an upper limit in Figure 2; J- and R-band measurements of the host galaxy are not available, again resulting in upper limits in Figure 2. As originally concluded by Reichart (1999), this SFD is consistent with that of SN 1998bw, after transforming it to the redshift of the burst, $z = 0.695$ (Djorgovski et al. 1999), and correcting it for Galactic extinction along its line of sight (see Reichart 1999 for details).

In Figure 2 (right panel), we plot the same distribution, but minus the *modeled*

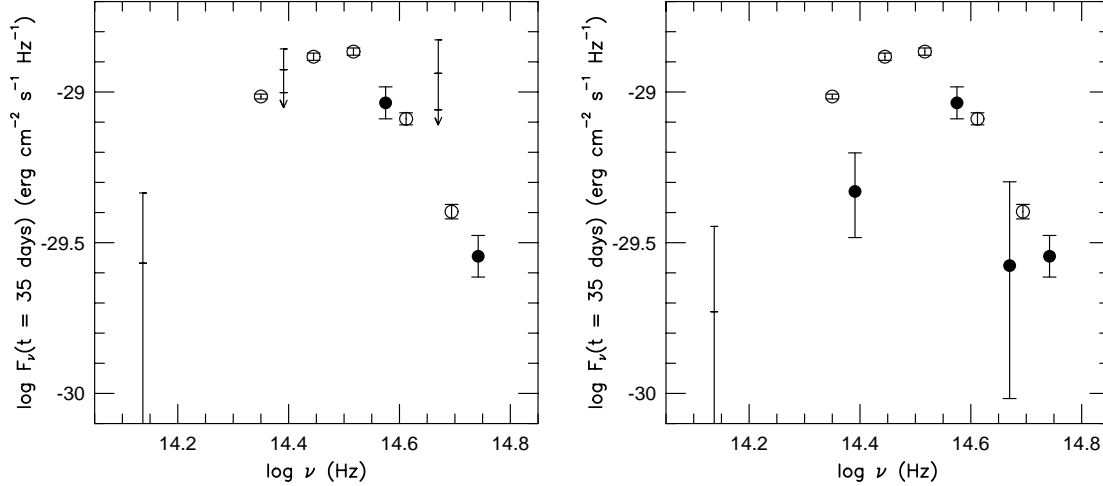


FIGURE 2. The K- through V-band SFDs of the late afterglow of GRB 970228 after subtracting out the observed (left panel) and modeled (right panel) SFDs of the host galaxy from Figure 1 and correcting for Galactic extinction (filled circles and upper limits), and the I- through U-band SFD of SN 1998bw after transforming to the redshift of GRB 970228, $z = 0.695$, and correcting for Galactic extinction (unfilled circles). The K-, J-, and R-band upper limits are 1, 2, and 3 σ .

SFD of the host galaxy from Figure 1. The SN-like component to the afterglow is detected in the J band, and possibly in the R band. The J-band measurement suggests that the SN-like component is $\approx 1/2$ mag fainter, and $\approx 1/2$ of a photometric band bluer, than SN 1998bw; however, this difference in J-band spectral fluxes is significant only at the $\approx 2.5 \sigma$ level. When possible photometric zero point errors and uncertainties in our spectral synthesis model of the SFD of the host galaxy are included, this difference is significant only at the $\approx 2 \sigma$ level. However, it is suggestive of what is generally expected: the Type Ic SNe that are theorized to be associated with bursts (e.g., Woosley 1993) are not expected to be standard candles.

THE NON-DETECTION OF A SN-LIKE COMPONENT TO THE AFTERGLOW OF GRB 990510

Given the rapid rate at which the afterglow of GRB 990510 faded, $t^{-2.4}$ (Stanek et al. 1999) or $t^{-2.2}$ (Harrison et al. 1999), at late times after the burst, a SN1998bw-like component to the afterglow, if present, could have dominated the light curve after about a month at red and NIR wavelengths (Figure 3; Lamb & Reichart 1999). However, Fruchter et al. (1999b) find no evidence of such a component, to within a factor of 3 – 7 in brightness, from two broadband *HST*/STIS observations.

Caution is in order before one concludes that a SN was not associated with GRB 990510, or one uses the non-detection of SN1998bw-like components to afterglows to place lower limits on the redshifts of bursts. In the case of GRB 990510, the

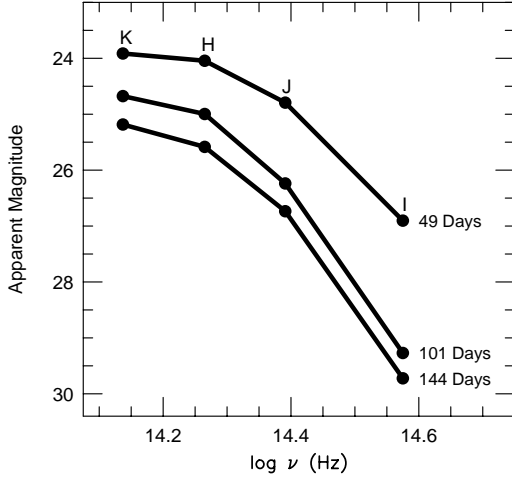


FIGURE 3. The SFD of SN 1998bw, transformed to the redshift of GRB 990510, $z = 1.619$, and corrected for Galactic extinction along the line of sight (see Lamb & Reichart 1999 for details). Had NICMOS not run out of cryogen half a year earlier, the presence or absence of a SN component to the afterglow of this burst could have been firmly established.

above calculation requires that assumptions be made about (1) the form of the SFD of the afterglow at the times of the observations, since the observations spanned a wavelength range of 300 – 900 nm; (2) how to extrapolate the non-power-law light curve of the early afterglow to the times of the observations; e.g., Stanek et al. (1999) and Harrison et al. (1999) do this differently; (3) the range of the luminosity distribution of SNe associated with bursts, relative to the luminosity of SN 1998bw, since these SNe are not expected to be standard candles; (4) the SFD of SN 1998bw at ultraviolet wavelengths, since the redshift of this burst is $z = 1.619$ (Vreeswijk et al. 1999); (5) whether differences in host galaxy extinction along the SN 1998bw and GRB 990510 lines of sight can be ignored; and (6) the underlying cosmological model.

GRBS AS BEACONS TO LOCATE SUPERNOVAE AT VERY HIGH REDSHIFTS

If bursts are indeed associated with SNe, then the first bursts should have occurred shortly after the first stars formed, at redshifts of $z \approx 15 - 20$ (Ostriker & Gnedin 1996; Gnedin & Ostriker 1997; Valageas & Silk 1999). Lamb & Reichart (1999) show that bursts and their afterglows should be detectable out to these very high redshifts. One way, of many (see Lamb & Reichart 1999 for details), in which bursts can be used to probe the early universe is to use them as beacons to locate SNe at very high redshifts.

In Figure 4, we plot the V-band light curve of SN 1998bw added to the best-fit source-frame V-band light curve of the early afterglow of GRB 970228 from Reichart (1999), transformed to various redshifts and corrected for Galactic extinction (see Lamb & Reichart 1999 for details). We use the V band because SN 1998bw peaked in this band. Clearly, the peak of the SN component of the light curve can be detected, at least from space, out to the K band, which corresponds to a redshift of $z \approx 3$. The peak cannot be detected at longer wavelengths since such faint

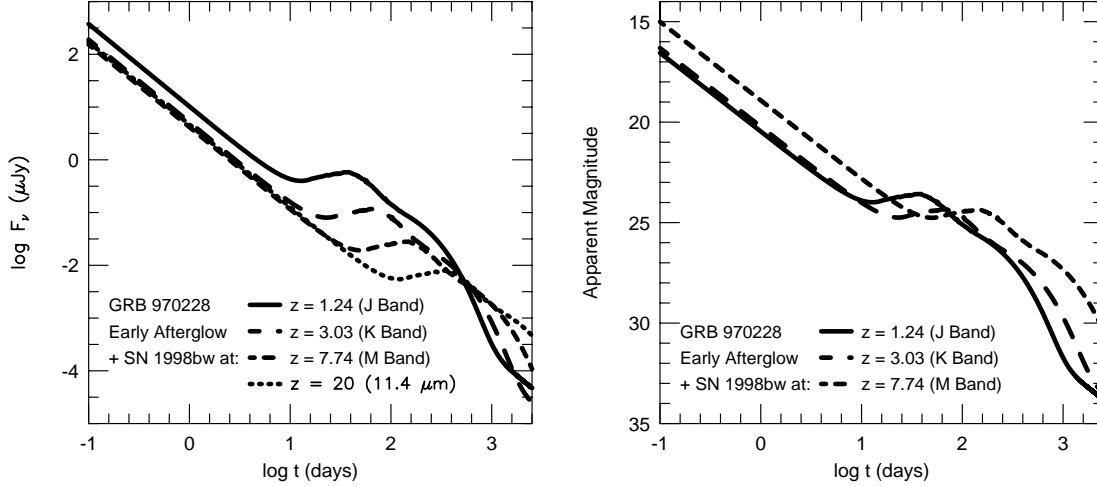


FIGURE 4. V-band light curve of SN 1998bw added to the best-fit source-frame V-band light curve of the early afterglow of GRB 970228 from Reichart (1999), transformed to various redshifts and corrected for Galactic extinction

magnitudes cannot be reached in the L and M bands. However, from the K band, one should be able to detect SNe like SN 1998bw blueward of the peak out to redshifts of $z \approx 4 - 5$.

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